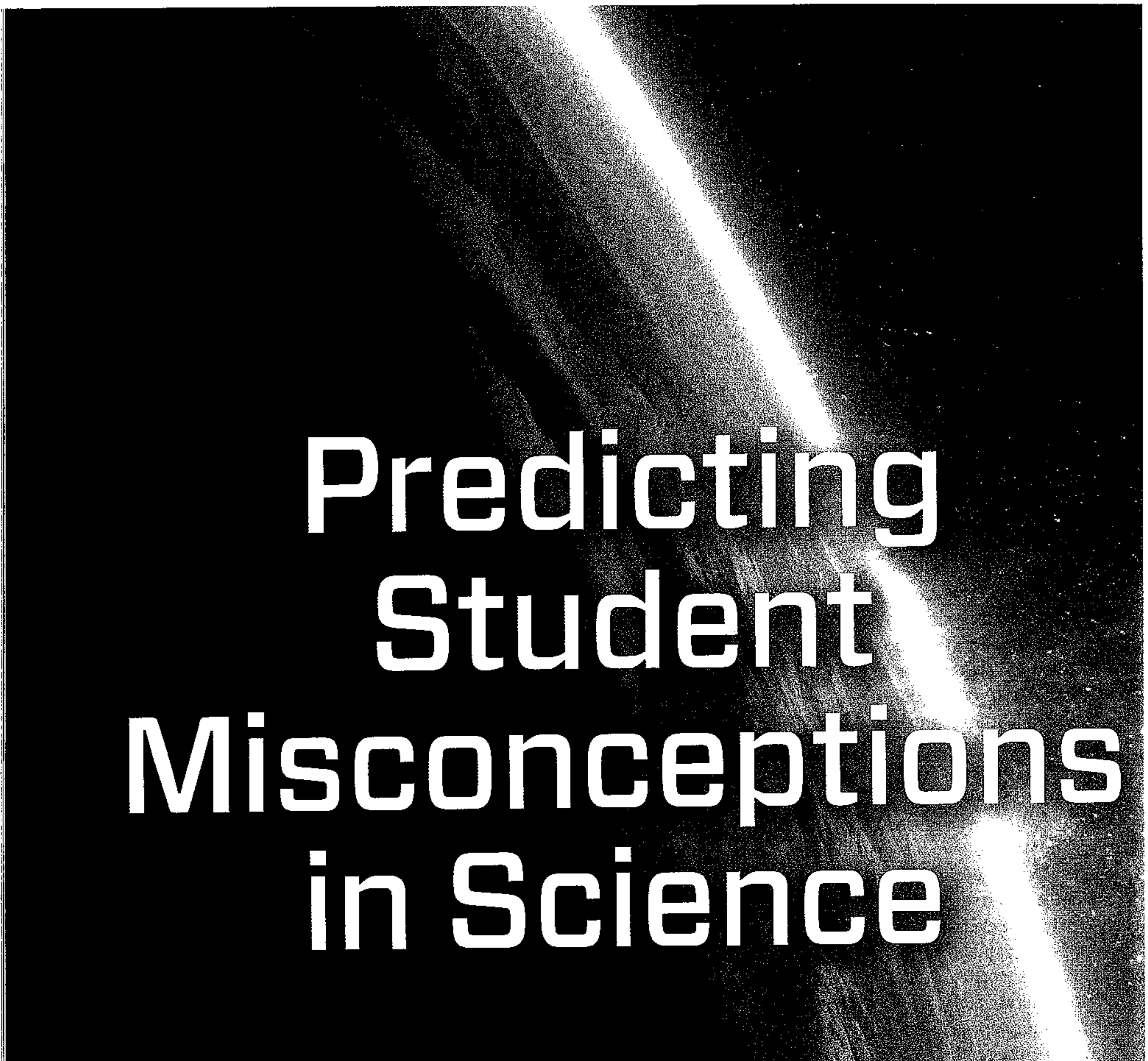


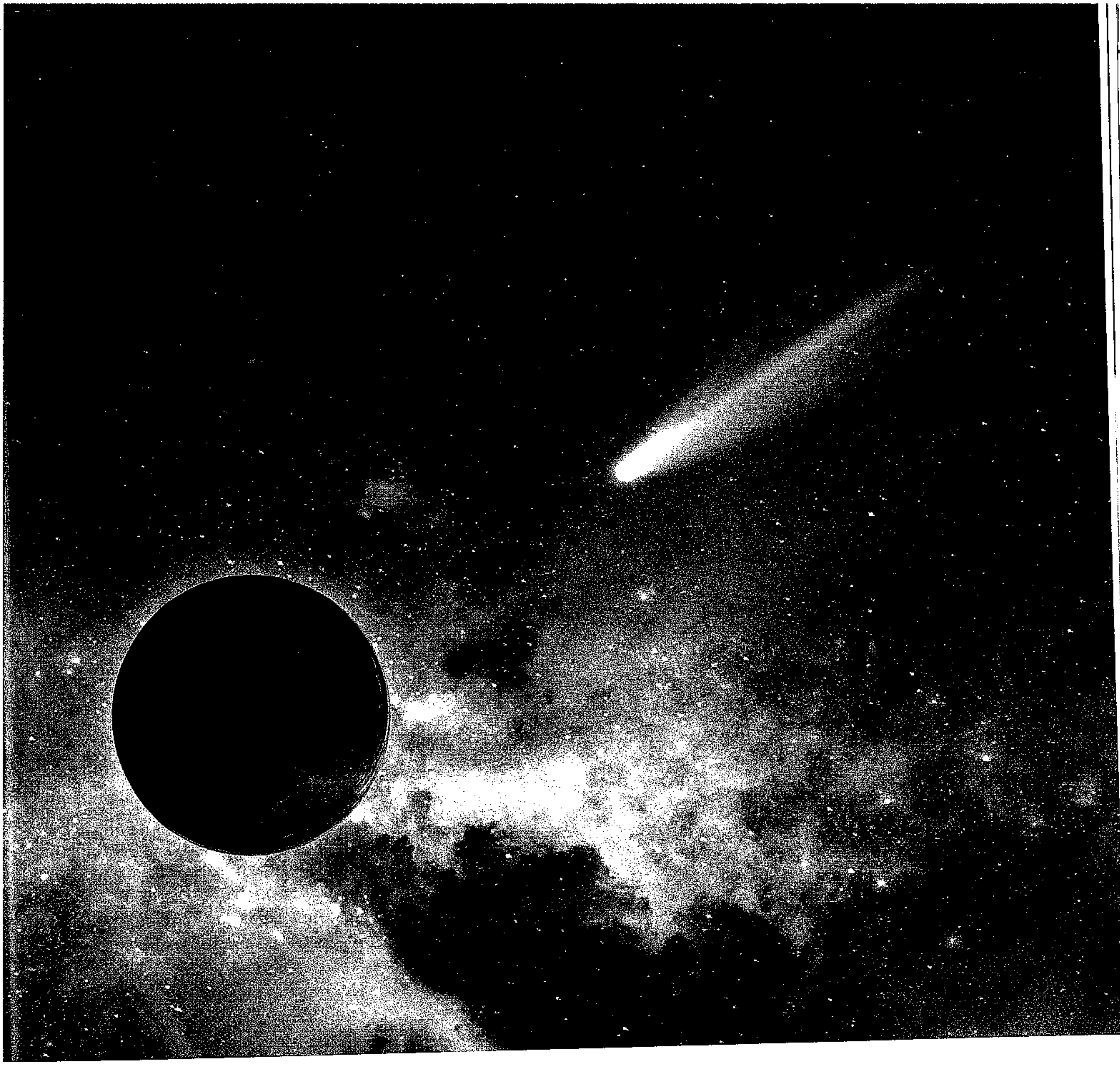
Predicting Student Misconceptions in Science

Students come to us with perceptions about how the world operates. Savvy questions teach them to think more deeply.

Jaunine Fouché

Two key challenges in science instruction are identifying the naïve conceptions and misconceptions students hold and getting past those misconceptions. To illustrate, let me begin with a story.

Early in my teaching career, I would sometimes go into my school at night when it was empty and I could get work done. My 5-year-old daughter would often come with me and play while I worked. She and I would always walk down the long corridor from



my classroom, passing through a set of double doors that were usually open, to the cafeteria to get a snack from the machine (a time-honored practice known to parents worldwide as bribery). One night we were there later than usual, and these doors were closed. My daughter went running ahead of me, curls bouncing and—with no signs of slowing—ran smack into the closed doors, bouncing off them and landing on her bottom.

I was dumbfounded. After picking her up, I asked her why she hadn't slowed down. She said she thought the doors would open by themselves like she'd seen other doors do when you get close to them. When I asked her what she would do next time she saw a set of closed doors, she replied that I should run ahead and make sure the doors were open for her. As a parent, this wasn't exactly the response I was looking for, but such is the mind of a 5-year-old.

My point in sharing this story is that students come to us with perceptions about how their world operates,

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perceptions shaped by their experiences. In my daughter's case, experiences gathered at the hospital, grocery store, and local mall had molded her perception.

Our students' perceptions, and the experiences feeding them, are as diverse as their backgrounds. The difficulty comes when students' experiences have produced misconceptions that conflict with concepts we're trying to teach. If we aren't aware of these misconceptions, we may set students up to run into the proverbial closed door.

I wanted them to understand that the amount of gravity in our galaxy isn't enough to account for the high orbital velocities of the stars near the galaxy's edge. Even stranger, stars moving at those high velocities should be escaping the galaxy's collective gravity and flying off into space—yet they stay in their orbits. This implies that something besides the visible mass we can detect in our galaxy is holding the galaxy together.

Before students could understand this "missing mass" dilemma, they had to have a foundational understanding

If teachers aren't aware of students' misconceptions, **they may set students up to run into the proverbial closed door.**

The gateway to effectively uncovering and changing students' misconceptions is predictive questioning. This strategy, used in conjunction with strategic discourse, is a powerful tool (Chin, 2007). Learning, especially the type of inquiry-based learning encouraged in science classrooms, is a socially mediated endeavor. Inquiry loses its punch without strategic discourse, whether that discourse is with the teacher or among students (Abell & Lederman, 2010). To get a sense of how using predictive questions to uncover misconceptions works, let's examine a lesson I recently taught my 12th grade astronomy students.

Busting Myths About Gravity

I hoped this lesson would lead students to an understanding of the evidence for dark matter in space.

of gravity. The lesson started with helping them grasp the law of universal gravitation,

$$F=G\frac{m_1m_2}{r^2}$$

which tells us that the force of gravity (F) is affected by two things: mass (*m*) and proximity (*r*). The force of gravity gets stronger if objects have more mass and if objects are closer together; the converse of each statement is also true.

Students needed to understand that gravity acts as a tether holding objects together, that objects can overcome their gravitational tether when they achieve high enough velocities, and that the gravitational effects we see within galaxies can't be accounted for by looking solely at the mass from luminous matter (matter that can be detected on the electromagnetic spectrum). I used carefully planned questions to lead them toward these understandings.

I began by asking each student to *predict* the orbital velocities of something familiar to them—the planets in our solar system (What happens to the orbital velocity of the planets as they get farther and farther from the sun?). I also asked them to *explain* their reasoning, providing a graphical as well as verbal explanation; they would later observe data on these orbits and revise their explanations as necessary.

These questions were folded into a protocol that I call the *predict–explain–observe–revise cycle*—modified from White and Gunstone's (1992) predict–observe–explain strategy. Students predict the outcome of a potentially discrepant event; explain their reasoning (including graphically if they are looking at the relationship between variables); observe the actual phenomenon or data; and engage in strategic discourse in small groups—which leads them to revise their explanations based on the evidence.

As I expected, most students predicted that orbital velocities would increase as planets got farther from the sun, giving explanations similar to that shown in Figure 1. In physics class, they had learned about linear velocity, which explains that when an object spins around, the outside part of that object spins faster than the inner part. I suspected I would have to reveal—and break down—students' misconceptions so they would realize that this principle doesn't apply to the individual orbits of planets and stars.

Next, students collected and observed and graphed actual data on the orbital velocity of our planets. Finally, in small groups they evaluated this data, talked together about what might explain it, and revised their explanations for the orbital velocities.

Once students' misconceptions about gravity and objects spinning in space were uncovered, each group was able to use its discussion and consideration of the new data to come to more accurate explanations. Students took responsibility for mediating the discussions. Occasionally, when a group wasn't quite there yet, I'd drop in and engage one group member in this kind of questioning:

TEACHER: I heard you say something interesting about the planets and stars. Would you be willing to share it with me?

STUDENT: Sure. I was positive that the planets would get faster the farther they got from the sun, but they didn't.

TEACHER: Why did you think that?

STUDENT: Because we learned in physics that a ball at the end of a string spins faster and faster the longer the string is.

TEACHER: Let me see if I understand what you're saying. Let's think of a DVD spinning around inside a DVD player. You're saying that the part of the DVD closest to the center spins slower than the part of the DVD that's near the edge?

STUDENT: Yeah. But that's not what the planets did. They got slower as they got farther away from the sun.

TEACHER: What could explain that?

STUDENT: I don't know.

TEACHER: What formula do we have that explains how matter behaves gravitationally?

STUDENT: The law of universal gravitation. Oh! The planets get farther and farther away from the sun, so gravity decreases.

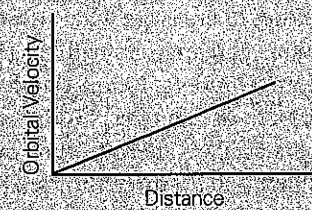
TEACHER: Why isn't that the same as the DVD?

STUDENT: Because the DVD is one solid thing, but the planets are all separate.

At no point did I need to give away answers: I only needed to ask predictive questions, provide data for students to analyze, and ask students to expand on their thinking by talking within their groups.

FIGURE 1. Sample Student Work in First Part of Lesson on Dark Matter

Predict: What happens to the *orbital velocity of the planets* as they get farther and farther from the Sun? Draw your prediction on the graph at right:

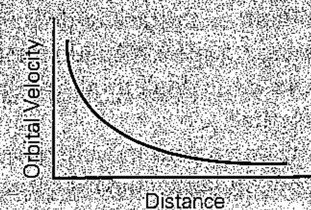


Explain: Why do you think this? Explain your logic:

As the planet gets further from the sun the velocity of the planet gets faster because it's like a string tied to a ball, the outside of the string gets faster, or moves faster. The planets have more mass so more gravity is on them.

Observe: Look at the actual orbital velocities of planets as they get farther and farther from the sun. Draw your revised orbital velocity curve on the graph below:

$F = G\frac{m_1 m_2}{r^2}$ → Matters more



Revise: Revise your explanation in light of this new evidence.

Gravity doesn't work like a string because the string is all one thing so all of the string has to make it around in the same amount of time no matter how far from the center it is. So the outside is faster than the inside. But planets' speeds work by gravity, and the further away from the Sun, the weaker gravity is so they slow down. Some planets do have more mass, which is a direct relationship to gravity, but distance is way more important because it's inverse squared. So they get slower when they are further away.

Getting to Powerful Questions

Predictive questioning with strategic discourse is especially powerful when students hold firm misconceptions. Every year in my physics class, I have students who swear that shooting a marble straight up in the air before it lands on a runway will cause it to go the farthest down that runway. It isn't until the marble hits them on the head, and they answer a few pointed questions, that they realize that shooting an object straight up only gives it height, not distance. If I simply told them this would happen, it wouldn't have nearly the impact.

Any well-structured, inquiry-based lesson is rooted in careful questioning. Like Carnac the Magnificent on the old Johnny Carson show, effective teachers can predict the most generative questions to ask—as well as the answers students are most

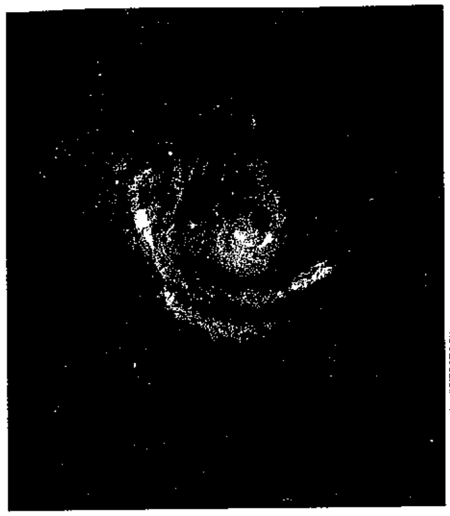
likely to give—not because they're mind readers, but because they have thought deeply enough about the lesson to envisage what those questions and answers will be (Di Teodoro, Donders, Kemp-Davidson, Robertson, & Schuyler, 2011). Savvy teachers prepare ahead of time questions that will do three things: elicit prior knowledge, uncover student misconceptions, and move students toward their conceptual goal.

Notice I didn't say you should give the answers—only that you should predict what the answers will be. It can be incredibly tempting to move this process along by giving students the answers when you see them struggling. But it's a mistake to do so in an attempt to spare them discomfort or because you don't think you have enough time.

Write down your most important questions and carry the list around with you as you check in with student groups. This way, you'll be sure to ask each important question to each group. Occasionally, these well-crafted questions still won't be enough to elicit the understanding you are targeting. It's important to dig deeply for understanding because we as teachers are so familiar with the content that we may lose track of how difficult it is for students to grasp the content. This phenomenon, called the *expert blind spot* (Fisher & Frey, 2010), can be avoided with savvy prediction about where students might get stuck.

When a learner does get stuck, it's essential to have a follow-up question or cue that will scaffold that student's conceptual awareness and point toward the targeted content. Consider this dialogue:

> TEACHER: What's a nocturnal animal?
>
> STUDENT: An animal that stays awake all night.



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> TEACHER: Tell me more about that. Does a nocturnal animal have special characteristics?
>
> STUDENT: Well, it doesn't sleep a lot. [misconception]
>
> TEACHER: I'm thinking of those pictures we saw of the great horned owl and the slow loris in the daytime and at night. Does your answer still work? (Fisher & Frey, 2010, p. 15).

This teacher wanted to uncover a student's misconception that nocturnal animals sleep very little. So she drew attention to photos the student had seen that showed such creatures sleeping in the daytime. Had the teacher stopped at her first question, she never would've uncovered the underlying misconception. And had she not had her follow-up prompt prepared, she would've missed a perfect opportunity to push the student to examine his or her own thinking rather than having that thinking corrected by the teacher.

It's powerful to reframe questions to use the word *you*. Imagine that after a student sees a discrepant event (such as a just-launched marble falling straight back down), you ask, "Why did that happen?" On the surface this seems like a legitimate question. However, it sets a student up for trying to explain the *right* answer and will likely reveal little about the mental models that learner holds. Instead, ask "Why do you think that happened?" or "What do you think will happen?" These questions encourage reflection and require the student to make his or her covert thinking visible—even if it isn't right.

Your probing could stop here. But remember, you're asking these questions because you've predicted that students harbor misconceptions that might warp the lens through which they view the content. It's good to ask a further question—like "Why do you think that?"—that enables you to uncover the underpinnings of students' thinking.

The reason to keep probing is like the reason to have a house professionally inspected before buying it. The house might look fine on the outside, but on closer inspection you discover the foundation is riddled with termites. The earlier you know, the sooner you can do something about it.

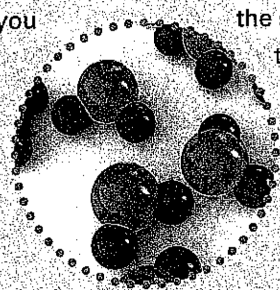
Using the Cycle in Layers

The predict–explain–observe–revise cycle can be used in layers. For instance, in the first part of my dark-matter lesson, I used the cycle with a concept that was familiar to the students. After this cycle was completed and students' misconceptions had been addressed, we began a second cycle with content that wasn't familiar. This second cycle took advantage of the conceptual work done in the first cycle to "feed forward" students' learning.

In this second cycle, I asked students to predict the orbital velocities of stars beyond our solar system, stars located farther and farther away from the galactic center. Every student predicted that these stars' velocities would slow down with increasing distance

NOW THAT'S A GOOD QUESTION!

How Many Water Molecules Fit in Your Mouth?



Students can't look up the correct answer if you ask a question that has no correct answer. I do this all the time by asking Fermi-type questions in class. A Fermi question is a question that, at first glance, seems impossible to answer. The students must use educated guesses and estimation skills to submit their best answer based on sound reasoning. It is important that the students show all of their work.

For example, at the end of a measurement unit in science class, I show the students a picture of a cement truck and a pair of dice, and ask them, "What is the weight of the cement truck measured in board game dice?" I ask my chemistry classes, "How many water molecules can you fit in your mouth?" and ask the students to submit a plan to actually test their answer. It is shocking how thorough they can be. Ask any math class, how many dollar bills are required to cover the surface area of the Atlantic Ocean. Show the students a world map and ask them to do it without a calculator.

My personal favorite for a Friday afternoon, great for many different classes, is "How many times can I listen to the song, 'I'm Gonna Be (500 Miles),' while actually walking 500 miles?" Play the song in the background to make things interesting.

—Ben Arcuri, chemistry teacher, Penticton Secondary School, Penticton, British Columbia

For more great questions suggested by our readers, see our "Tell Me About" column on p. 90.

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from the center, explaining their predictions with phrases like, "the more distance between the center of the galaxy and the stars, the less pull gravity has, so stars will orbit slower." They were amazed when I shared the actual data, which shows that orbital velocities increase and level out with distance. I also pointed out that stars orbiting at that velocity should be flying out of their orbits—yet they remain fixed.

As they discussed this data, student groups lit up with explanations. My questioning guided students back to their understanding of gravity, mass, and proximity, and their effects on orbital speeds. Eventually, each group decided there must be some sort of "missing mass" within the galaxies that holds them together and causes the orbital velocities of the outermost stars to remain high—but that this mass wasn't showing up on the electromagnetic spectrum. This led students to request additional information about the existence of dark matter and how it can be detected. For instance, one student revised her explanation like this:

> We decided there has to be more gravity to hold onto [the stars]. But we didn't know where it was coming from because we can't see anything else. A group member said it's dark matter, but we don't have any evidence (yet!) that it is.

Integral Tools

Strategic discourse and predictive questioning are integral to learning through inquiry in science classrooms. Used together, these tools tease out students' misconceptions, create opportunities for meaningful dialogue among students, facilitate higher levels of student engagement, and result in deeper learning. EL

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